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Search for non Standard Model Higgs boson decays in events with displaced muon-jets

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New light bosons that couple weakly to the standard model (SM) particles are predicted in various extensions of the standard model (BSM). Examples include supersymmetric (SUSY) theories with extended Higgs sectors or with a hidden valleys (dark SUSY). In these models the light bosons can be produced directly in the decay of a Higgs boson, or as part of the decay chain of SUSY particles. Depending on the branching fraction, the exotic decays of the SM-Higgs can be undetected in standard analysis techniques or due to its modified production cross section of the Higgs bosons at the LHC. Therefore, direct searches for non-SM decays of the Higgs boson are the fastest way to understand the nature of the Higgs boson. Either it will confirm its SM character, or it will rule out a whole array of BSM scenarios. We present status of the search at CMS for non-SM Higgs boson decays in events with displaced muon-jets.

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1 Introduction

The discovery of a scalar boson consistent with the standard model (SM) Higgs boson in 2012 was a milestone in particle physics [1, 2]. The discovery concluded a search that lasted nearly 50 years. The question still remains whether the long sought particle is in fact the SM Higgs boson. To answer this question, continued precision measurements of its properties must be carried out. In particular, the total SM branching ratio must be calculated with high precision. This could take several years of data taking. The current 95% confidence level (C.L.) upper limit on the non SM branching ratio is 32% [3]. An alternative way is to perform a direct search. Either an observation of a non SM Higgs is made or a wide range of beyond the SM scenarios (BSM) is excluded

This paper describes a search for a non SM Higgs boson which decays to new light bosons a [4]. The light bosons themselves decay to 2 muons. In addition, one or more particles (X) can be produced in the decay chain that escape detection. The full Higgs boson decay chain is thus $H \rightarrow 2a + X \rightarrow 4\mu + X$. This search is optimized to discover light bosons with masses between the dimuon mass and the ditau mass (between ~ 0.2 GeV and ~ 3 GeV) The analysis is designed in a such a way that the results are model independent. This allows an interpretation in many different models with boosted dimuons in the event topology. The results are interpreted in two BSM scenarios, a dark SUSY and an next-to-minimal SUSY (NMSSM) scenario.

The dark SUSY model is motivated by the observation of rising positron fraction cosmic rays up to 200 GeV cosmic ray energy [5]. The increase in positron fraction can be explained by annihilating dark matter particles. A $U(1)$ symmetry is modeled on top of SUSY, which is broken at the electroweak scale. The Higgs boson decays to SUSY neutralinos, which subsequently decay to dark neutralinos and neutral dark bosons. Since no positron excess is seen in cosmic rays, the dark boson mass is restricted below $2m_p$. The dark boson undergoes kinetic mixing with the SM photon, so that it can decay to light quarks and leptons. In particular when the mass is small, a large branching ratio to dimuons decays is expected.

New light bosons can also be explained within the framework of NMSSM. NMSSM has an extended Higgs sector with 7 Higgs bosons, 3 neutral CP-even states $h_{1,2,3}$, 2 neutral CP-odd states $a_{1,2}$ and 2 charged Higgs states H^\pm . The Higgs like scalar boson can be the lightest or the second lightest h_1 or h_2 . Both h_1 and h_2 can then decay to new light bosons a_1 . Since a_1 has a largely singlet nature it couples to the SM particles. In particular when the a_1 mass is between the dimuon mass and the ditau mass, one can expect a large branch ratio to muons [6].

2 Analysis method

The analysis is carried out on data taken with the Compact Muon Solenoid (CMS) at the Large Hadron Collider [7]. The CMS detector is designed to detect and reconstruct muons with excellent precision. Information from the tracking system and muon system is used in this analysis.

This analysis is a follow-up of two previous searches which were conducted at $\sqrt{s} = 7$ TeV [8, 9]. The results for this analysis ($\sqrt{s} = 8$ TeV) were submitted to Phys. Lett. B. [4]. Among the results for the 7 TeV analysis included limits on the production cross section times branching ratio squared $\sigma(pp \rightarrow h_{1,2} \rightarrow 2a) \times \mathcal{B}^2(a \rightarrow 2\mu)$. For prompt dimuons, dark photon masses between 2 muon masses and 2 GeV were excluded. New in this analysis is the addition of muon displacement, which is added at generation level for the Mont Carlo samples. Displacements are sampled according to an exponential with mean value 0 mm to 5 mm. The dark photon is related to the kinetic mixing ε_{kin} through [10]. Therefore, once can set limits in a 2D plane (ε_{kin} vs m_{γ_D}) [11].

3 Event selection

This analysis requires at least 4 muons. Online two muons are selected with a transverse momentum, p_T , of 17 and 8 GeV. The offline selection requires 4 muons with $p_T > 8$ GeV and pseudorapidity $|\eta| < 2.4$. At least 1 muon is required to be in the barrel region ($|\eta| < 0.9$) with $p_T > 17$ GeV. Muons that are close-by are clustered into pairs of dimuons, based on the vertex probability and the dimuon invariant mass. Exactly 2 dimuons are required in each event. There is however no limit on the number of additional unpaired muons. The dimuons are also required to have the same production origin. This translates to a cut on the vertex parameter $\Delta z < 0.1$ cm. Finally, the dimuons must have compatible masses, assuming that they are produced from the same kind of dark photons. A diagonal mass corridor is thus constructed in the dimuon-dimuon mass plane. Light SM resonances ($\rho, \omega, \phi, J/\psi$) are used to study the dimuon mass resolution. The dimuons are required to have a mass difference less than 5 times the mass resolution.

4 Displaced muons and pixel hit recovery

New in this analysis is the displacement of the muons. Muons are produced at a certain distance from the primary vertex. Because of this, the muons will leave fewer hits in the tracker. This results in a much reduced trigger efficiency for muons with a large displacement. To keep the analysis model-independent, a fiducial region in the CMS detector is constructed. Both dimuons are required to have at least 1

hit in the first layer of the barrel pixel or endcap pixel detector, corresponding to $L_{xy} < 4.4$ cm and $|L_z| < 34.5$ cm respectively. This ensures a model independent interpretation of the results. Despite the cut on L_{xy} , the analysis is still sensitive to proper displacements of 5 mm. The fiducial region for the analysis on 13 TeV will be extended to $L_{xy} \sim 20$ cm with the improved trigger.

An issue arises when displaced muons are reconstructed in CMS. Namely, when the two muons are highly-parallel and spatially close, the hits in the tracker system can end up being clustered into a single hit, which is not assigned to either muon. The dimuon will therefore fail selection. To recover these dimuons, a recovery technique was developed for this analysis. Muon trajectories are extrapolated to the first layer of the pixel detector. All nearby pixel hits are collected in a scan area around the two muons and in between them. If a hit was found in the scan area, the dimuon is recovered. This is shown in figure 1.

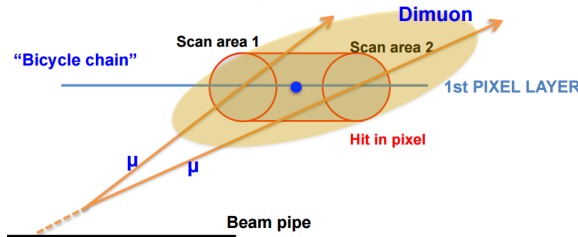


Figure 1: Diagram showing the pixel-hit-recovery mechanism developed for this analysis.

5 Results and interpretation

The most significant backgrounds for this analysis are $b\bar{b}$ decays into a pair of muons, via semi-leptonic decay of a b-quark and the daughter c-quark, or via light hadronic resonances ($\rho, \omega, \phi, J/\psi$), 2.0 ± 0.7 events. A secondary background is the electroweak production of dimuons ($pp \rightarrow Z/\gamma^* \rightarrow 4\mu$), 0.15 ± 0.03 events. Finally, there is also a minor background from prompt J/ψ production, 0.05 ± 0.03 events. After all selections, 2.2 ± 0.7 background events were selected. After the full event selection only one event survives in data. This is consistent with the number of background events. Figure 2a shows the selected data event (green triangle) and the events that pass all selections, except the dimuon mass constraint (white circles). A model independent limit can be set on $\sigma(pp \rightarrow h_{1,2} \rightarrow 2a) \times \mathcal{B}^2(a \rightarrow 2\mu)$. The results are shown in figure 2b. These results can also be interpreted in the two benchmark scenarios. Figure 3a shows the 95% C.L. upper limits on the dark SUSY model. Figure 3b shows the 95% C.L. upper limits on NMSSM.

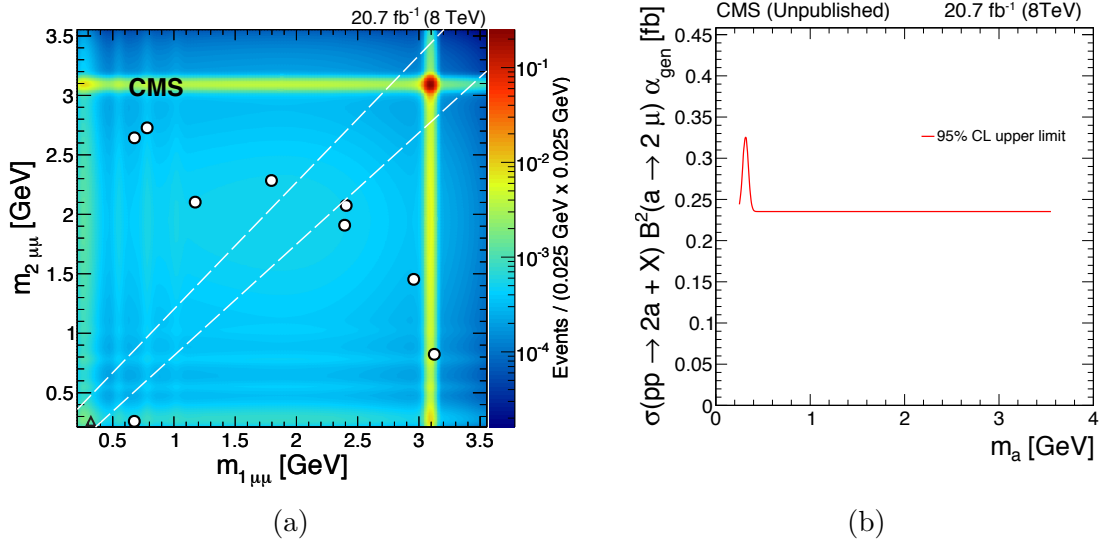


Figure 2: Left: Dimuon mass template for the signal event (green triangle) events that pass all selections, except the dimuon mass constraint (white circles). Right: Model independent 95% C.L. upper limit on $\sigma(pp \rightarrow 2a) \times \mathcal{B}^2(a \rightarrow 2\mu) \times \alpha_{\text{GEN}}$ versus m_a , where α_{GEN} is the generator level acceptance, which includes the fiducial cut ($L_{xy} < 4.4$ cm and $|L_z| < 34.5$ cm).

6 Conclusions

A search for non-SM Higgs decays to new light bosons in events with displaced muon-jets was presented. One event was observed in 20.7 fb^{-1} of CMS data. This is consistent with the SM expectation of 2.2 ± 0.7 background events. A 95% C.L. model independent limit was set on $\sigma(pp \rightarrow 2a) \times \mathcal{B}^2(a \rightarrow 2\mu)$. The results are applicable to a whole range of non-SM scenarios. In particular they were interpreted in two benchmark models, dark SUSY and NMSSM. This analysis will be continued in CMS run-2 with an improved trigger, suitable for displaced muons.

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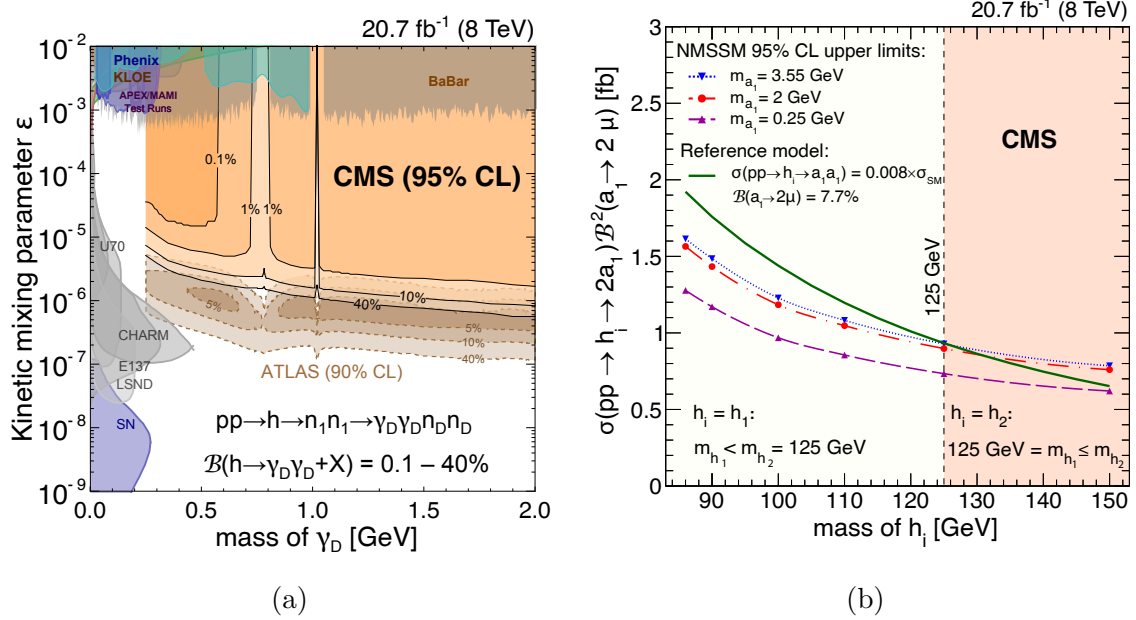


Figure 3: Left: 95% C.L. upper limits (black solid curves) on $\sigma(pp \rightarrow h \rightarrow 2\gamma_D + X) \times \mathcal{B}^2(\gamma_D \rightarrow 2\mu)$ in the plane of the kinetic mixing parameter ϵ_{kin} and the dark photon mass. The colored contours represent different values of $\mathcal{B}(\gamma_D \rightarrow 2\mu)$ in the range 0.1% to 40%. Exclusion limits from other experiments are shown as well. The rapidly varying C.L. as function of γ_D is caused by the strong variations of $\mathcal{B}(\gamma_D \rightarrow 2\mu)$. The results from this analysis are complementary to the ATLAS analysis [11]. Right: 95% C.L. upper limits in the range $86 < m_{h1} < 125$ GeV and $125 < m_{h2} < 150$ GeV on $\sigma(pp \rightarrow h_{1/2} \rightarrow 2a_1) \times \mathcal{B}^2(a_1 \rightarrow 2\mu)$ for a_1 boson masses 0.25 GeV (dashed curve), 2 GeV (dashed-dotted curve) and 3.55 GeV (dotted curve). This is compared to the predicted rate from a simplified model (solid curve) with an invisible BSM fraction of 0.8%. This yields an upper limit on the branching fraction $\mathcal{B}^2(a_1 \rightarrow 2\mu)$ of 7.7%.

References

- [1] CMS Collaboration, *Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC*, Phys. Lett. B, 716 (2012), p.30.
- [2] ATLAS Collaboration, *Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC*, Phys. Lett. B, 716 (2012), p.1.
- [3] CMS Collaboration, *Precise determination of the mass of the Higgs boson and tests of compatibility of its couplings with the standard model predictions using proton collisions at 7 and 8 TeV*, Eur. Phys. J. C **75**, no. 5, 212 (2015).

- [4] CMS Collaboration, *A search for pair production of new light bosons decaying into muons*, Submitted to Phys. Lett. B [arXiv:1506.00424v1 [hep-ex]]
- [5] AMS Collaboration, *High Statistics Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5500 GeV with the Alpha Magnetic Spectrometer on the International Space Station*, Phys. Rev. Lett. **113** (2014) 121101.
- [6] R. Dermisek and J.F. Gunion, *New constraints on a light CP-odd Higgs boson and related NMSSM ideal Higgs scenarios*, Phys. Rev. **D81** (2010) 075003.
- [7] CMS Collaboration, “The CMS experiment at the CERN LHC,” JINST **3** (2008) S08004.
- [8] CMS Collaboration, “Search for Light Resonances Decaying into Pairs of Muons as a Signal of New Physics,” JHEP **1107** (2011) 098.
- [9] CMS Collaboration, “Search for a non-standard-model Higgs boson decaying to a pair of new light bosons in four-muon final states,” Phys. Lett. B **726** (2013) 564.
- [10] C. Cheung, J. T. Ruderman, L.-T. Wang and I. Yavin, *Kinetic mixing as the origin of light dark scales*, Phys. Rev. **D80** (2009) 035008.
- [11] ATLAS Collaboration, “Search for long-lived neutral particles decaying into lepton jets in proton-proton collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector,” JHEP **1411** (2014) 088. [arXiv:1409.0746 [hep-ex]].